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STATUS OF THE MAST EXPERIMENT

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INTRODUCTION

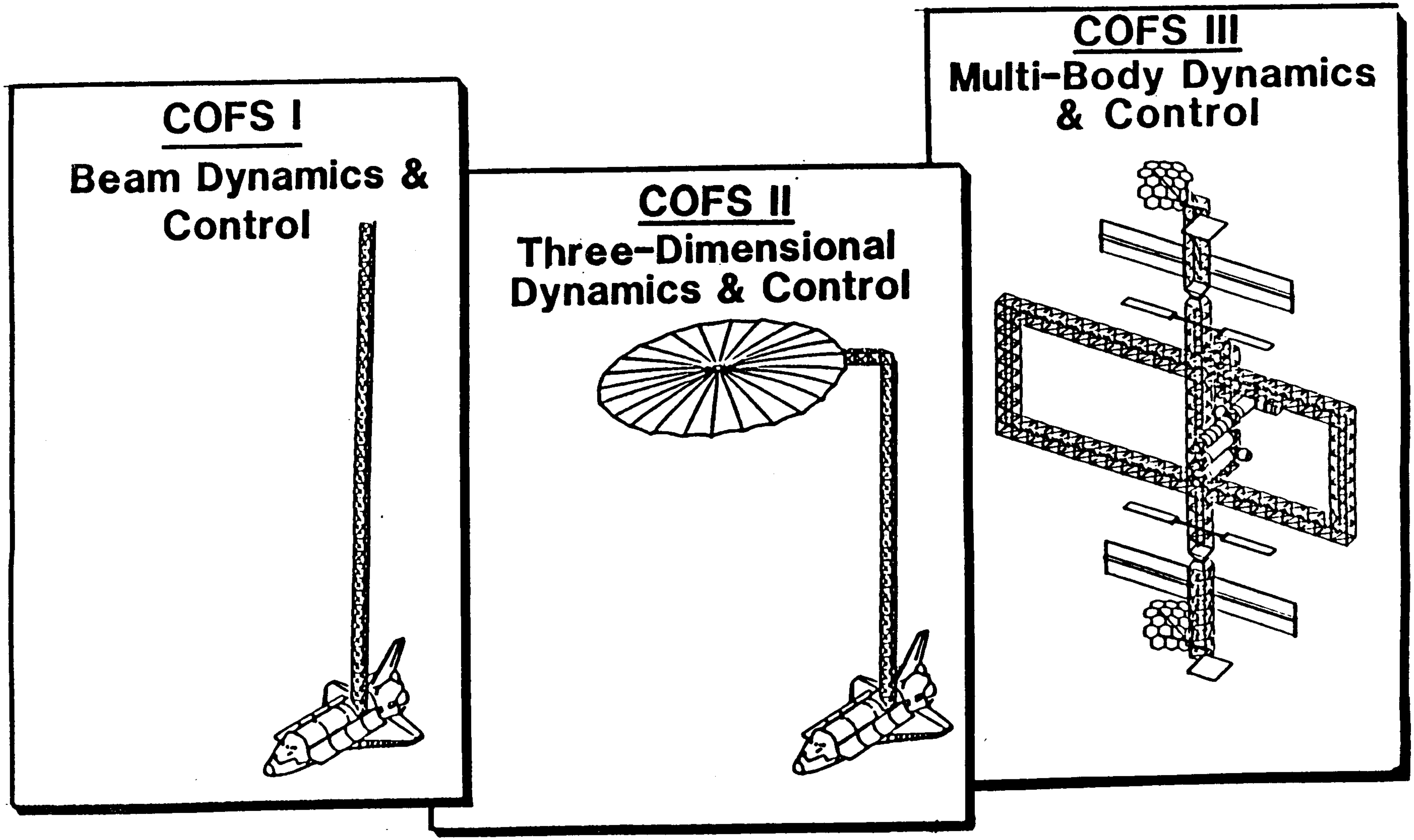
The control of flexible structures is a research topic of high interest and importance in developing future spacecraft, particularly very large or very rapidly maneuvered craft. It is an interdisciplinary problem that involves combining advanced structural dynamics analysis and identification techniques with advanced control methods. Many sophisticated mathematical control techniques for flexible structures have been devised. The basic problem is that most of them require a relatively accurate mathematical model of the system under control including the dynamics of both the structure and the control system components. Obtaining such a model for either subsystem traditionally has required great effort including a significant validation step based on test data. This is complicated further in the interdisciplinary case by the fact that the control system is using the mathematical model to decide where, when and how hard to apply forces, in a fraction of a vibratory oscillation. Requirements on the accuracy and the computational speed of the mathematical calculations in the control computer are far greater than, say, a dynamic loads analysis or a rigid-body control maneuver. Iteration and updating based on measured responses becomes an on-line part of the control process. Instability is a constant threat, especially for higher frequency modes or poorly measured/modelled responses.

Because of the quantum increase in complexity over proven methods, promising techniques for the control of flexible structures must be validated in actual hardware experiments before committing to their use in actual spacecraft missions. The Mast experiment system serves as a focus for such validation. It is the first in a series of experiments under the Control of Flexible Structures (COFS) Program at the NASA Langley Research Center.

THE CONTROL OF FLEXIBLE STRUCTURES (COFS) PROGRAM

The Mast hardware is being developed for the COFS-I Project under the COFS Program. The figure shows the currently envisioned hardware foci for the first three projects under this program. Beginning with a 60m shuttle-orbiter-attached, deployable beam for COFS I, the complexity of structures advances with each level. COFS II adds a three-dimensional motion aspect with rigid-body slewing of a flexible body attached to the Mast structure. Both COFS I and COFS II are planned for both ground and in-orbit tests to calibrate the usefulness of ground tests in the validation process. The planned COFS III hardware is a ground test article which is a scale model of Space Station. Refined calibration of the ground experiments is expected to be made using orbital data obtained as a natural part of Space Station development rather than by special flight experiments.

CONTROL OF FLEXIBLE STRUCTURES PROGRAM



CONTROL OF FLEXIBLE STRUCTURES - COFS I TECHNOLOGY GOALS

The COFS I hardware is intended to provide hardware for general experimentation by the Control Structures Interaction (CSI) research community, including government, academia and industry. As such, it is designed to accommodate a variety of potential research objectives and technology goals. The figure overviews the primary goals.

Several facets of hardware testing and analysis are planned in order to achieve the desired research results. The 60m beam shown on the previous figure is to be tested dynamically on the ground and in orbit. Both excitation/identification and controls tests are planned using proof-mass actuators located at the tip of the beam and at three locations along its length. A capability for exciting/measuring/controlling 10 flexible modes is baselined. Tests on substructures, joints and control components are planned to assist in the development of refined analyses. In addition, scale models will be tested (in ground tests only) to ascertain the validity of using such models to reduce gravity effects in ground tests of proposed flight systems.

CONTROL OF FLEXIBLE STRUCTURES

COFS I TECHNOLOGY GOALS

- VALIDATE GROUND TEST METHODS
- DEVELOP & VALIDATE IN-SPACE TEST METHODS
- VERIFY CSI ANALYTICAL TOOLS
- ASSESS SCALING EFFECTS
- EVALUATE DISTRIBUTED CONTROLS METHODS

COFS I (MAST) FLIGHT SYSTEM

The Mast flight hardware is currently being designed under contract with Harris Corporation, overviewed in the accompanying figure. The beam, being developed under a subcontract to Astro Aerospace Corporation, is a foldable-longeron graphite epoxy structure with titanium joints. It is of statically determinate design and is intended to be unaffected structurally by temperature changes. A control system consisting of distributed sensors, actuators, control computer and associated data handling equipment is being designed to allow experiments in structural dynamics and a wide variety of vibration control methods. Detailed design has been under way for about six months with a final design completion expected in 1987.

COFS I (MAST) FLIGHT SYSTEM

CONTRACT – AWARDED NOVEMBER 25, 1985

PRIME CONTRACTOR – HARRIS CORP., MELBOURNE, FL

SUB CONTRACTORS

- ASTRO AEROSPACE – BEAM/DEPLOYER
- DELCO – EXCITATION/CONTROL COMPUTER
- SCI SYSTEMS INC. – GROUND SUPPORT EQUIPMENT
  – HOUSEKEEPING COMPUTER

DURATION* – 36 MONTHS + 12 MONTHS POST–DELIVERY SUPPORT

PRODUCTS – FLIGHT SYSTEM INCLUDING BEAM, SENSORS, ACTUATORS AND ELECTRONICS; MATHEMATICAL MODELS AND SIMULATOR; GROUND SUPPORT EQUIPMENT

*MAY BE AFFECTED BY RECENT 10–MONTH SLIP OF LAUNCH DATE TO OCTOBER 1990.

MAST FLIGHT SYSTEM SIMULATOR (MFSS)

In order to develop algorithms for excitation and control of the COFS I system, a dedicated ground simulator is being developed. Real time simulation of all significant dynamic effects including actuators, structure and computer delays is to be included. This simulator will serve for determining the best candidate algorithms as well as for validating software during development.

MAST FLIGHT SYSTEM SIMULATOR (MFSS)

OBJECTIVE:

PROVIDE A DEDICATED COMPUTER WHICH PERMITS REAL-TIME SIMULATION OF STRUCTURAL DYNAMIC RESPONSE TO ACTIVE CONTROLS

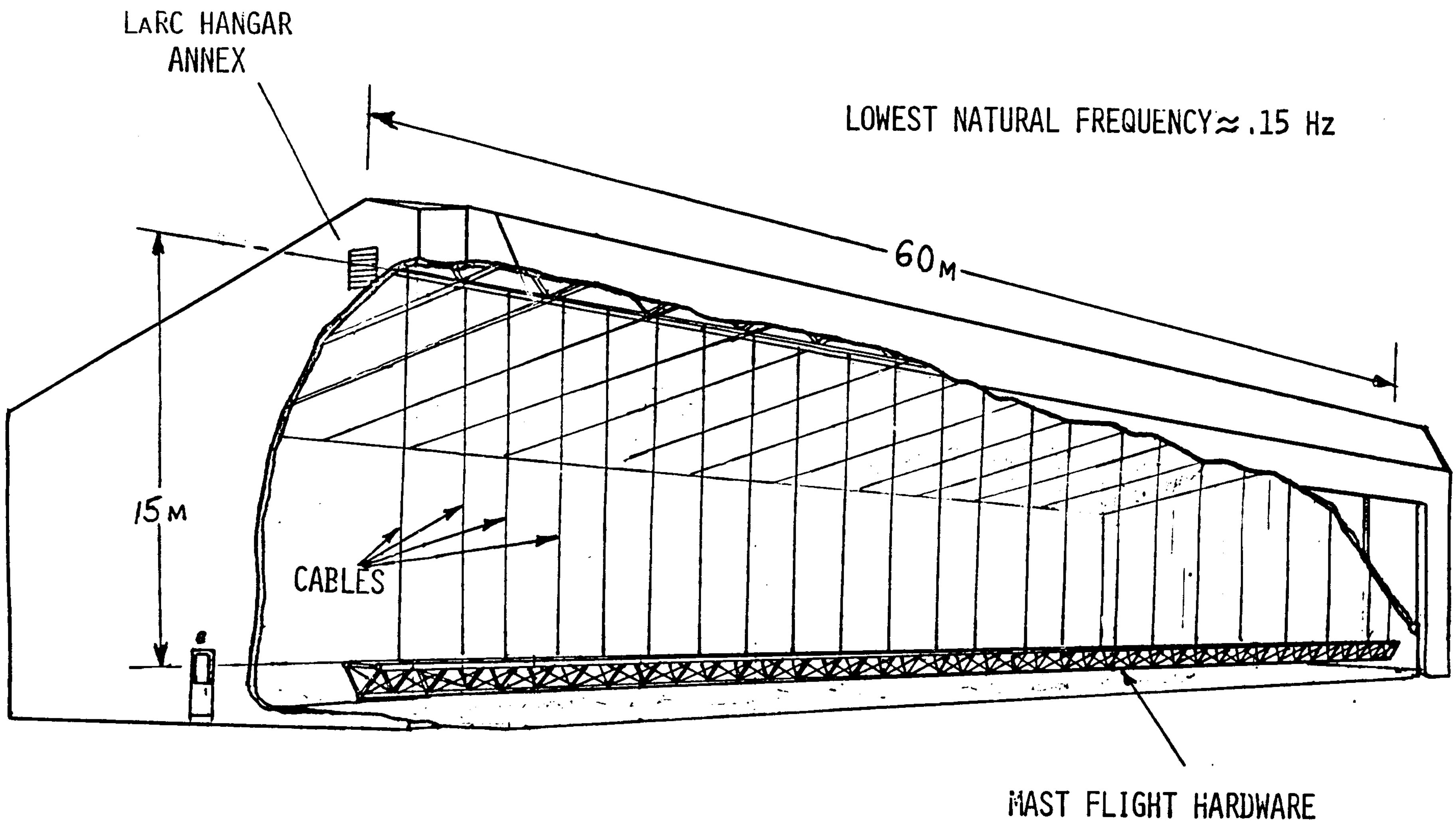
PURPOSE:

- VALIDATE CONTROLS ALGORITHM SOFTWARE
- SUPPORT FLIGHT ALGORITHM SELECTIVE PROCESS

MAST GROUND TEST CHALLENGES STATE OF THE ART

Validation of mathematical models and control designs by ground tests has been a traditional standard. However, as lightweight space structures become large in dimension, gravity effects combined with low-frequency/high-amplitude response combine to significantly degrade the quality of the test. Traditional soft suspensions used to support the structure for test must have combined properties of low mass, low stiffness and large displacement excursions which are well beyond the state of the art. The alternative is to conduct tests to validate mathematical models which include suspension system dynamics and to analytically remove the suspension system effects to predict on-orbit performance. This too is not a well-developed technology. The Mast systems will be dynamically ground tested as shown in the figure using a relatively interactive suspension which requires careful modeling to extract its effects. Thus ground testing technology development is an integral part of the program.

MAST GROUND TEST CHALLENGES STATE OF ART



20M LABORATORY BEAM (MINI MAST)

In order to develop mathematical modeling and test techniques for the Mast hardware in advance of flight hardware delivery, a 20m laboratory beam called the Mini Mast is being built. It is based on an early design and is similar to the flight Mast in geometry but has somewhat different joint kinematics. Early static, dynamic and controls tests using this beam in various test configurations will be conducted. Also tests of joints and suspension techniques will be conducted to better understand the importance of these factors in mathematical modeling.

20M LABORATORY BEAM (MINI-MAST)

- DEPLOYABLE; GRAPHITE & TITANIUM; SIMILAR TO FLIGHT BEAM
- BEING BUILT BY ASTRO AEROSPACE.
- TO BE USED FOR PRELIMINARY DEVELOPMENT OF ANALYSIS, CONTROL & TEST METHODS

COFS I - BEAM DYNAMICS & CONTROLS TECHNOLOGY SCHEDULE

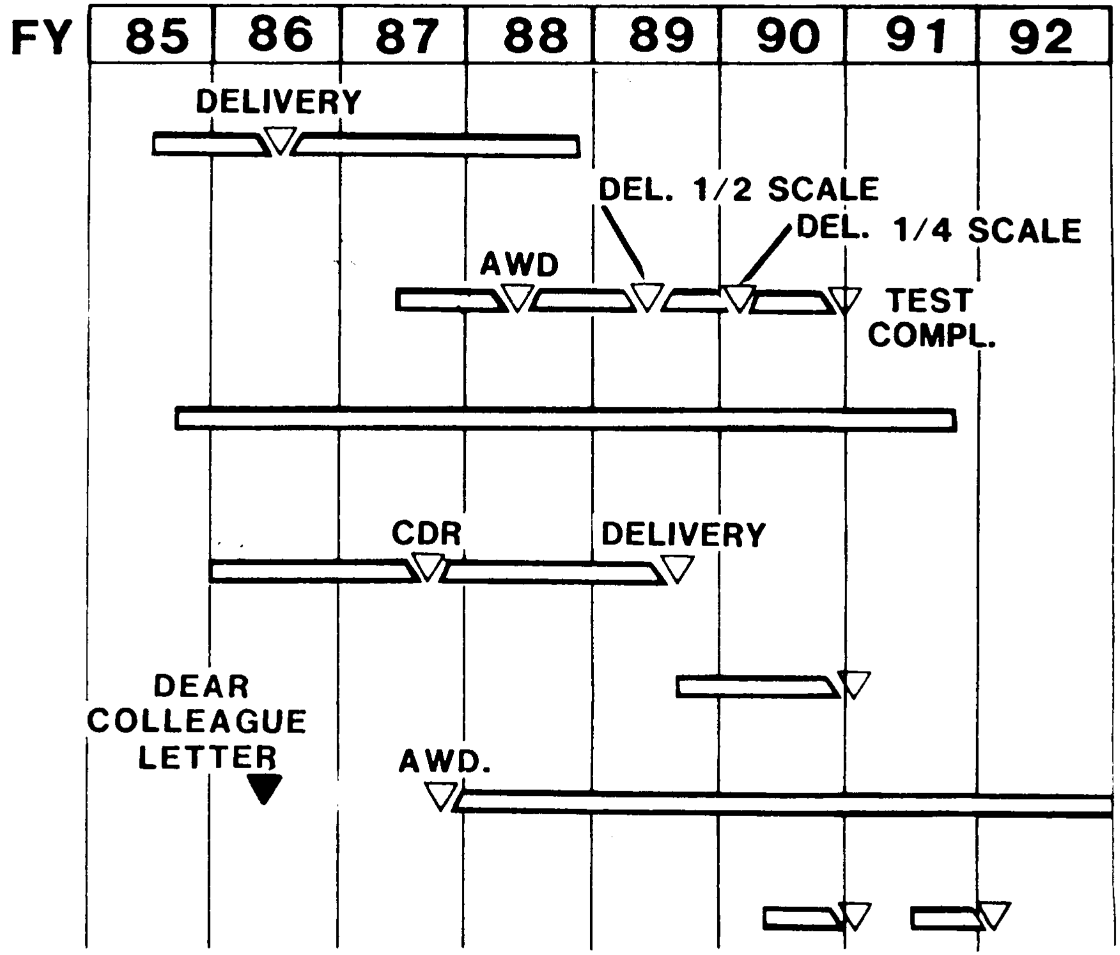
The attached figure shows the preliminary schedule for the COFS I Program as of May 1986. This schedule is likely to be modified as further information on the space shuttle flight schedule becomes available. As currently planned, the Mast hardware would be delivered to NASA, where the ground model tests will be conducted, in mid-1989. The first flight would occur in late 1990 with a second to follow one year later. The first flight would emphasize structural dynamics and system identification with relatively simple controls experiments. The second flight would permit more advanced control algorithms to be tested on the same hardware, taking advantage of the improved knowledge of the system dynamics obtained from the first flight.

CONTROL OF FLEXIBLE STRUCTURES

COFS I - BEAM DYNAMICS & CONTROLS TECHNOLOGY

MAJOR TASKS

- MINI-MAST 20M BEAM DESIGN, FABRICATION & TEST
- SCALED MODEL DESIGN, FABRICATION & TEST
- EXPERIMENT MODELING, SIMULATION & SOFTWARE DEVELOPMENT
- MAST FLIGHT SYSTEM DESIGN & FABRICATION
- MAST FLIGHT SYSTEM GROUND TEST
- GUEST INVESTIGATORS PROGRAM
- MAST FLIGHT TESTS



PRELIMINARY

GUEST INVESTIGATOR PROGRAM

Because the Mast is an experimental apparatus for testing/validating analytically developed tools, the opportunity for participation by the research community is being made available. This program is overviewed in the figure. Participation is possible in a variety of roles ranging from receiving and analyzing data to development of control algorithms for on-orbit experiments.

GUEST INVESTIGATOR PROGRAM

OBJECTIVE:

TO PROVIDE OPPORTUNITIES FOR AND PROMOTION OF GENERIC RESEARCH BOTH GROUND AND IN-SPACE AMONG INDUSTRY/UNIVERSITY AND GOVERNMENT FOR THE DEVELOPMENT OF CONTROLS/STRUCTURES INTERACTION TECHNOLOGY

APPROACH:

ESTABLISH GROUND AND IN-SPACE FACILITIES WHICH PROVIDE FOR INDIVIDUAL AND/OR COMPANY EXPERIMENTS AT MINIMUM COST

PAYOFF:

- BROAD BASE FOR ADVANCED CSI METHODOLOGIES
- DISSEMINATION OF PROGRAM DATA & FINDINGS WITHIN CSI COMMUNITY
- IN-SPACE RESEARCH AWARENESS

GUEST INVESTIGATOR OPPORTUNITIES

Some examples of typical guest investigator studies as listed in the figure. Potential studies are not limited to these activities. Studies which do not require hardware changes are most likely to be acceptable because of the cost and schedule impact involved in changing space qualified hardware. A Call for Proposals has been issued with final proposals due on August 29, 1986. These proposals are technically "unsolicited" and hence discussion of their nature and objectives, as well as possible implementation problems, with NASA investigators is allowed on an individual basis.

GUEST INVESTIGATOR OPPORTUNITIES

(TYPICAL)

- STRUCTURAL DYNAMICS
- FLEX-BODY CONTROL ALGORITHMS
- SYSTEM IDENTIFICATION ALGORITHMS
- FLIGHT & GROUND TEST METHODS
- MATH MODELLING
- VIBRATION SUPPRESSION
- ANALYSIS OF GROUND & IN-SPACE TEST DATA
- FLIGHT TESTING OF UNIQUE HARDWARE

COFS I GUEST INVESTIGATOR (GI) PROGRAM
PROPOSAL EVALUATION CRITERIA

The primary factor in selection of proposals for the GI program is technical merit. The figure shows, however, that other factors are important in order to keep the activity manageable and to maximize benefit to the technical community.

COFS I GUEST INVESTIGATOR PROGRAM

PROPOSAL EVALUATION CRITERIA

1. TECHNICAL MERIT
2. RELEVANCE TO COFS GOALS
3. PROGRAMMATIC ISSUES
   - COST
   - ACCOMMODATIONS
   - MIX OF EXPERIMENTS
   - TECHNOLOGY NEEDS
4. INVESTIGATOR/ORGANIZATION EXPERIENCE

GUEST INVESTIGATOR SELECTION PROCESS
COMMITTEE STRUCTURE

The selection of participants in the GI program will be made by four committees as shown in the figure. Initial ratings of all proposals and suggested selections will be made by a Technical Evaluation Committee comprised of nine members from four NASA Centers and the Jet Propulsion Laboratory. No more than two voting members from any one Center will be involved. After the initial technical selection, the proposals will be reviewed for cost and management factors by a Business Evaluation Committee. Also, an Accommodations Committee will screen the selected proposals for possible adverse safety, hardware integration and schedule incompatibility factors which may require changes or rejection of the proposal. Finally, an Experiments Evaluation Committee will review findings and recommendations of the other committees and make a final prioritized recommendation to the NASA Headquarters Control Structures Interaction Steering Committee, which makes final selections. This selection process is due to be completed in the first quarter of 1987 with final contract/grant awards made approximately four months later.

GUEST INVESTIGATOR SELECTION PROCESS

COMMITTEE STRUCTURE

COMMITTEE	MEMBERS	RESPONSIBILITIES
• TECHNICAL EVALUATION	CHAIRMAN: COFS PI JSC JPL MSFC LaRC GSFC	• TECHNICAL ASSESSMENT • CATEGORIZE • PRIORITIZE
• BUSINESS EVALUATION	CHAIRMAN: COFS BUSINESS MANAGER LANGLEY STAFF PRICING COST ANALYSIS CONTRACTS	• EXPERIMENT COST • PRICING CONTROL • MANAGEMENT STRUCTURE
• ACCOMMODATIONS EVALUATION	CHAIRMAN: COFS PROJECT MANAGER MSFC JSC	• ACCOMMODATIONS • INTEGRATION • SAFETY
• EXPERIMENTS EVALUATION	CHAIRMAN: LaRC DIRECTOR FOR SPACE MSFC LaRC JSC JPL GSFC	• FINDINGS TO CSI STEERING COMMITTEE

COFS GI PROGRAM-FUNDING PLAN

The funding plan for the COFS I GI program, as of May 1986, is shown in the accompanying chart. This plan is based on the original expected flight date in late 1989. However, some spreading out of the funding to cover the expected October 1990 flight date is likely to occur. In any case, the total funds available is about $4M. This will be distributed among investigators and will undoubtedly control the total number of investigators supported. Opportunities for cost-sharing through memorandums of understanding will be explored where mutual benefit warrants.

COFS GUEST INVESTIGATOR PROGRAM

FUNDING PLAN*

INVESTIGATOR FUNDS, $,K

	FY87	88	89	90	BTC	TOTAL
COFS I	400	850	1250	1300	200	4000

FLIGHT SOFTWARE DEVELOPMENT FUNDS, $,K

COFS I	-	1400	2400	200	-	4000

*MAY BE AFFECTED BY RECENT 10–MONTH SLIP OF LAUNCH DATE TO OCTOBER 1990.

SUMMARY

A flight experiment apparatus for the in-orbit study of structural dynamics and control issues is being built under contract. This apparatus, a 60M-long deployable truss-beam with distributed proof-mass actuators, is planned for flight on board the space shuttle in the early 1990's. It is being designed to accommodate structural dynamics, system identification and active vibration suppression experiments and is backed by a comprehensive ground test program. Participation as experiments by members of the research community is being made available in a Guest Investigator program. Opportunities exist in a variety of specific technical areas including structural modeling, test techniques, control algorithm design and parameter estimation as well as many others. The ultimate goal is the validation and/or verification of critical analytical developments to the point that they may be considered flight ready.

SUMMARY

- MAST EXPERIMENT IS COMBINED GROUND TEST, ORBITAL FLIGHT TEST AND ANALYSIS OF A DEPLOYABLE BEAM UNDER THE COFS PROGRAM
- PROVIDES VEHICLE FOR RESEARCH IN STRUCTURES STRUCTURAL DYNAMICS, AND CONTROL ISSUES
- CONTRACT FOR FLIGHT SYSTEM IS UNDER WAY
- GUEST INVESTIGATOR PROPOSALS BEING ACCEPTED FROM UNIVERSITIES, INDUSTRY, AND GOVERNMENT